Effects of Impact Dehuller Rotor Speed on Dehulling Characteristics of Diverse Oat Genotypes Grown in Different Environments

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ABSTRACT

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Commercial processing of oats for human consumption generally requires impact dehulling to isolate groats from the hull. Impact dehulling involves feeding oat grain into the center of a spinning rotor that expels the grain against the walls of the dehuller. The force of the impact breaks the hull from the groat. We have tested the effect of rotor speed on dehulling efficiency, groat breakage, and unbroken groat yield on 18 oat genotypes from replicated plots in six different environments. Dehulling efficiency and groat breakage increased with rotor speed with all genotypes and environments, but there were significant genotypic and environmental effects as well. In general, genotypes with higher test weight and kernel density dehulled more efficiently at slower rotor speeds. Oat genotypes with higher oil and protein concentrations in their groats tended to break less during dehulling. Oats from hotter, drier environments suffered greater groat breakage. Maximal unbroken groat yield represented a balance between dehulling efficiency and groat breakage, but groat proportion and dehulling efficiency appeared to be the most important factors contributing to groat yield.

The oat kernel or grain consists of a caryopsis or groat and a hull, made of the lemma and palea (Fulcher 1986; White 1995). The hull usually must be removed before the grain can be processed for human consumption. Commercial oat processing generally utilizes the impact dehuller for this purpose (Cleve 1948; Stuke 1955; Deane and Comers 1986; Ganssmann and Vorwerck 1995). During impact dehulling, grains are fed into the top of a spinning rotor, which expels the grain against the wall of the dehuller. The force of the impact causes the hull to break away from the groat and the lighter hulls can then be removed by aspiration. Rotor speed can be adjusted to optimize milling yields.

Not all oat grains are dehulled in a single pass through an impact dehuller. We define dehulling efficiency as the proportion of oat grains that are dehulled during a single pass through an impact dehuller (Doehlert and Wiessenborn 2007). Brückner (1953) and Brückner et al (1956) addressed this as "geschälte Korner" or "whole groats" in their early studies of impact dehulling. Browne et al (2002) referred to this as "hullability" in their study with a compressed air dehuller. Dehulling efficiency increases with increasing impact rotor speed, which seems logical as more highly accelerated grains would strike the impact walls with greater inertial energy. But increased rotor speed also results in more broken groats. Some food applications require intact groats for improved value. High proportions of broken groats can reduce the value of the final products. To maximize unbroken groat yield, a suitable rotor speed must be used for maximal dehulling efficiency but minimal groat breakage.

In an earlier study from this laboratory, we examined the influence of kernel size on optimal rotor speed for groat yield. We separated oats by width, length, and density. At slow rotor speeds, the most efficient dehulling occurred when the kernels were either the largest by width or shortest in length. The size fractions with the highest test weight dehulled most efficiently at slower rotor speeds (Doehlert and Wiessenborn 2007).

Since that study, we developed a method to measure kernel envelope volume by sand displacement (Doehlert and McMullen 2008). We determined that ≈78% of the observed variation in test weight was due to variation in kernel density, and the remaining 22% to packing efficiency. It implies that the improved dehulling efficiency associated with higher test weight is due to the increased kernel density.

Although our earlier study utilized three oat cultivars, the experimental design did not allow for comparison of dehulling characteristics among genotypes. In this study, we specifically tested the hypothesis that the genotype and environment affect dehulling characteristics. The objectives of this study were to identify physical kernel characteristics associated with genotypes and environmental factors associated with improved dehulling characteristics.

MATERIALS AND METHODS

Plant Material

Sixteen oat (*Avena sativa* L.) cultivars (AC Assiniboia, Beach, Brawn, CDC Dancer, Gem, HiFi, Killdeer, Leonard, Maida, AC Morgan, Morton, Otana, AC Pinnacle, Ronald, Triple Crown, and CDC Weaver) and two breeding lines (ND021612, ND030291) were grown at three U.S. locations (Carrington, Fargo, and Williston) in North Dakota in 2005 and 2006. A seeding rate of 2.47×10^6 kernels/ha was used for all experiments. Herbicide treatments consisted of preemergence application of 3.93 kg of propchlor/ha and postemergence application at the three-leaf stage with a tank mix of 0.14 kg of thifensulfuron/ha, 0.07 kg of tribenuron/ha, and 0.14 kg of clopyralid/ha. Experimental units consisted of four rows spaced 0.3 m apart and 2.4 m long. The two center rows were harvested with a two-row binder and then threshed with a plot thresher. The harvested grain was cleaned using a clipper (model 400, Office Tester, Bluffton, IN) and cleaner fitted with a 4.75×19 mm oblong hole sieve and with aspiration adjusted so that kernels containing a groat were not removed. The sieve removed grain <2 mm in width.

Impact Dehulling

Four 50-g samples from each lot were placed in 450-mL glass jars. Grain moisture was determined by measuring the mass loss in a 2-g grain sample after 2 hr at 130°C in a convection oven. Moisture of grain was then adjusted to 9% by adding water to the grain in the jars, sealing for 24 hr, and shaking at intervals.

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The North Dakota State University Agricultural and Biosystems Engineering Department in Fargo manufactured the impact dehuller to resemble a commercial dehuller. It consisted of a 50-cm diameter, 12-vane rotor and a granite impact ring. Rotor speed was controlled with a variable frequency drive and calibrated with a tachometer. Rotor speeds of 1502, 1661, 1807, and 1949 rpm corresponded to peripheral speeds of 39.3, 43.5, 47.3, and 51.0 m/sec (Doehlert and Wiessenborn 2007). Samples (50 g) equilibrated to 9% (db) moisture were poured by hand into the dehuller at a rate of ≈200 g/min. Dehulled samples were collected at the bottom of the dehuller. Free hulls were initially removed by passing the sample through a laboratory aspirator (Kice Metal Products, Wichita, KS) and afterwards passing the sample through a Bates type laboratory aspirator (Seedboro, Chicago IL). Hulls were discarded without examination. Immediately after aspiration, the mass of the crude groats were recorded and the sample was stored in paper envelopes until sorting.

To account for moisture changes during storage, the mass of crude groat samples was measured at the time of dehulling and immediately before sorting. Moisture correction factor (MCF) was calculated by dividing the original sample mass by the current sample mass (Doehlert and McMullen 2001). Samples were then sorted by hand into whole groats (G), broken groats (B), and oats resistant to dehulling (R). Groat percentage (%GP) was corrected for the oats resistant to dehulling

$$\%GP = \left[\frac{[(G+B)\times MCF]}{[WO-(R\times MCF)]}\right]\times 100 \tag{1}$$

where WO is the whole oat mass (with hulls). Dehulling efficiency (DHE) was the percentage of oats dehulled with a single pass through the dehuller. DHE and percent broken groats (%B) were calculated according to Doehlert and McMullen (2001)

$$DHE = 100\frac{[WO-(R\times MCF)]}{WO} \tag{2}$$

$$\%B = 100\left[\frac{B}{(G+B)}\right] \tag{3}$$

Unbroken groat yield (%GY) of individual fractions was G as a percentage of WO after one pass through the dehuller

$$\%GY = 100\left[\frac{G\times MCF}{WO}\right] \tag{4}$$

Groat yield (%GY) was calculated at each of the four rotor speeds for grain from every experimental plot. The rotor speed that provided the highest groat yield from that plot was defined as the optimal rotor speed for that plot. Mill yield (%MY) was calculated as

$$\%MY = 100\left[\frac{(G+B)\times MCF}{WO}\right] \tag{5}$$

$$\%MY = \left[\frac{\%GP}{100}\times\frac{DHE}{100}\right]\times 100 \tag{6}$$

Physical Analyses

Physical characteristics of grain, including test weight, mean kernel mass, mean kernel volume, mean kernel density, mean groat mass, mean groat volume, mean groat density, mean hull mass, mean hull volume, mean hull density, mean kernel length, mean kernel width, and mean kernel image area were determined as described earlier (Doehlert and McMullen 2008). Oil analysis was performed on whole groats (Oxford 4000 NMR, Abingdon, England). The NMR signal was calibrated with known masses of vegetable oil. Groats were dried at 130°C for 18 hr before the NMR signal was obtained. Protein was analyzed by combustion analysis with a nitrogen analyzer (FP-428, Leco, St. Joseph, MI). Total nitrogen was converted to protein as N × 6.25. Total (1→3),(1→4)-β-D-glucan (beta-glucan) was determined by the method of McCleary and Glennie-Holmes (1985). All composition data are expressed on a dry weight basis.

Weather Data

Weather data was gathered by automated weather stations located within 1,000 m of the field plots. They were managed by the North Dakota Agricultural Weather Network (NDAWN) and the results were obtained online (http://ndawn.ndsu.nodak.edu). Weather data used for analyses included monthly means of daily maximum air temperature, daily minimum air temperature, daily average air temperature, solar radiation, potential evapotranspiration, and total monthly rainfall.

Experimental Design and Statistical Analyses

Field plots were arranged in a randomized complete block design with three replicates. Analysis of variance was performed using the SAS computer package (v.9.1 SAS Institute, Cary, NC). Years and locations were combined as environments and replicates were considered nested in environments. Analysis of variance was applied to data where genotype and environment effects were considered random and rotor speed was fixed. Test of significance for treatments and their interaction effects were performed by combining the appropriate linear combination of mean squares using PROC MIXED procedure with DDFM=Satterth option in the SAS computer package. Variance components were also estimated for the random effects by PROC MIXED procedure. Best linear unbiased prediction (BLUP) values of treatment means were calculated by ESTIMATE statement in the PROC MIXED. Separation for BLUP of means was evaluated by the least significant difference, which was calculated by the standard error and degree of freedom obtained by the ESTIMATE statement using SAS. Correlations were first calculated for characteristics within each environment using data from individual plots. A chi square test was performed to verify that correlation coefficients were not significantly heterogeneous across environments (Steel et al 1997). When heterogeneity was not observed, correlation coefficients were pooled over environments according to Steel et al (1997). Linear regressions and step-wise regressions were calculated from genotype × location means using the Statistix computer package (Analytical Software, Tallahassee, FL).

RESULTS AND DISCUSSION

Dehulling efficiency increased with increasing rotor speed for all 18 oat genotypes tested (Fig. 1). There was also significant variation in dehulling efficiency among genotypes. Results are divided among the three panels of Fig. 1 to allow for resolution of individual genotypes. CDC Dancer, Pinnacle, and Beach exhibited the highest dehulling efficiency at the slowest rotor speed used. Differences among genotypes were much greater at the slow rotor speeds than at the faster rotor speeds. At the fastest rotor speeds, most genotypes had dehulling efficiencies of >90%. Proportionally, genotypes with the lowest dehulling efficiency at the slowest rotor speed increased the most at the highest speed. For example, DHE for Otana increased from 68% at the slowest speed to 90% at the fastest speed, which was an increase of 32%. In contrast, CDC Dancer had a DHE of 90% at the slowest speed and 98% at the fastest speed, an increase of only 9%. The improvement in DHE with rotor speed is genotype dependent.

Dehulling efficiency also increased with increasing rotor speed, but differently for different environments (Fig. 2).

Groat breakage increased in all genotypes tested with increasing rotor speed (Fig. 3). There were significant genotypic effects on groat breakage at all rotor speeds, and the genotypic ranking for groat breakage was largely consistent across all rotor speeds.

Amounts of broken groats of the 18 genotypes also increased significantly with increasing rotor speed (Fig. 4), and depended on environment. The highest breakage was observed at Williston and Fargo in 2006, both very dry environments for small grains in that year. Drought conditions could have made the oats more friable.

The response of groat yield to rotor speed among genotypes was complex (Fig. 5). Different genotypes showed different optimal dehulling rotor speeds. Groat yield represents a balance between dehulling efficiency and groat breakage. Both groat breakage and dehulling efficiency increased with rotor speed. Improved dehulling efficiency improved groat yield. Increased groat breakage decreased groat yield. Thus, genotypes such as CDC Dancer or AC Pinnacle, which dehulled easily at slow rotor speeds, had optimal groat yields at the slowest rotor speed used in this study. In contrast, some genotypes that dehulled poorly at slow speeds such as HiFi and Otana, exhibited much higher optimal rotor speeds for groat yield. Genotypes that were more resistant to dehulling also tended to be more resistant to breakage. Some of these genotypes, such as ND030291 and HiFi, exhibited relatively high groat yields at high rotor speeds, but most genotypes with high groat yields exhibited relatively slow optimal rotor speeds.

Groat yields were significantly different in 2005 and 2006 for the same rotor speed (Fig. 6). Samples from 2005, regardless of location, had higher groat yields and tended to have higher optimal rotor speeds. High groat proportions in the 2005 samples and greater breakage in many 2006 (which was a drier year) samples probably contributed to this trend.

Mill yield (Eq. 6) as presented here, is the product of groat percentage (as a decimal) and dehulling efficiency. Mill yield for many genotypes did not vary significantly with rotor speed (Fig. 7). Most of the genotypes where mill yield did increase with rotor speed were those that had very low dehulling efficiency at slow rotor speeds. Significant genotypic effects were evident on mill yield, and the genotypic rankings were largely consistent at all rotor speeds.

Environmental means for mill yield (Fig. 8) also showed an interesting segregation between environments from 2005 and 2006, similar to those seen in Fig. 6. This is probably also derived from the poorer groat percentage values in 2006 samples. Groat proportion determined at a constant rotor speed (1,661 rpm) for the samples analyzed here was presented in detail in an earlier report (Doehlert et al 2009).

Genotypic and environmental means of dehulling characteristics (%GP, DHE, %B, %GY, %MY) at optimized rotor speeds from this experiment are shown in Table I. The groat proportions

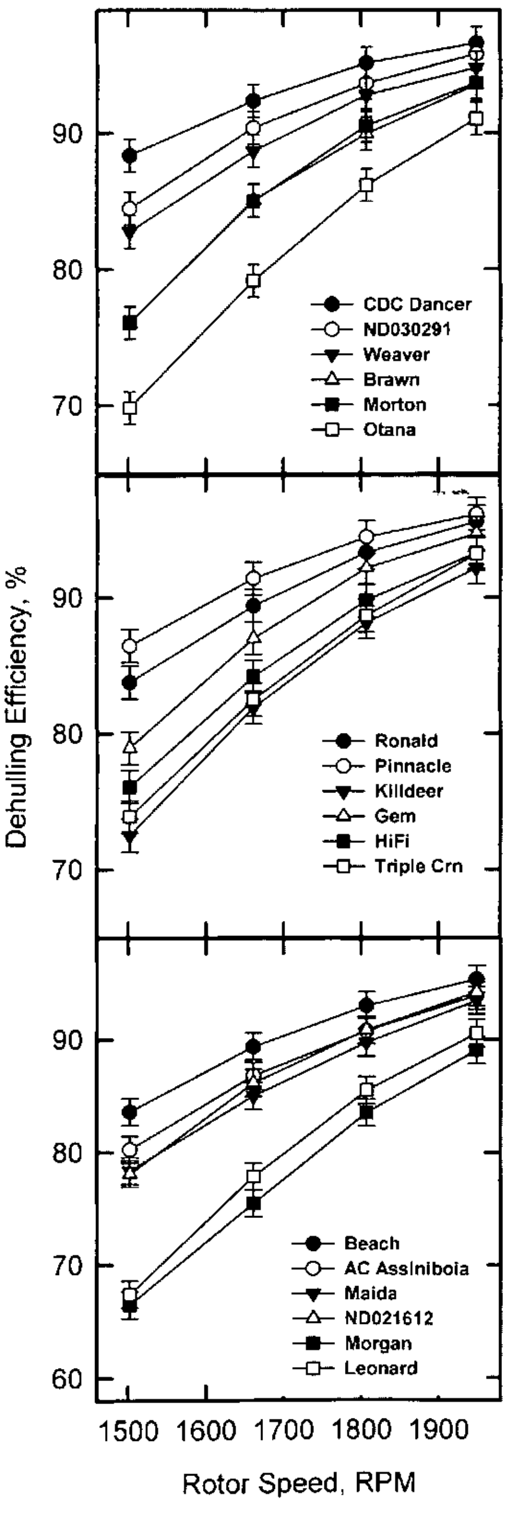

Fig. 1. Dehulling efficiency of 18 oat genotypes dehulled at four rotor speeds with an impact dehuller. Values are means estimated from best unbiased linear predictors from samples from six different environments. Error bars represent LSD (0.05) for genotype effect.

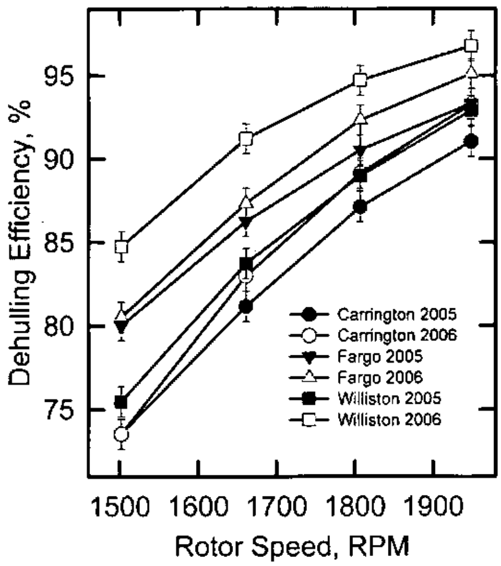

Fig. 2. Dehulling efficiency of oats grown in six different environments. Values are means estimated from best unbiased linear predictors from 18 genotypes. Error bars represent LSD (0.05) for environment effect.

were values obtained at the rotor speed that was optimal for groat yield and were variable among genotypes and environments. Genotypes with the highest groat proportion at optimal rotor speed, such as CDC Dancer, Ronald, Pinnacle, and Weaver were also highly ranked in dehulling efficiency, % broken groats, groat yield, and milling yield and dehulled optimally at slower speeds than most other genotypes. Likewise, genotypes that exhibited poorer groat proportions in the environments used in this study also had lower dehulling efficiency, % broken groats, groat yield and milling yield and dehulled optimally at faster rotor speeds.

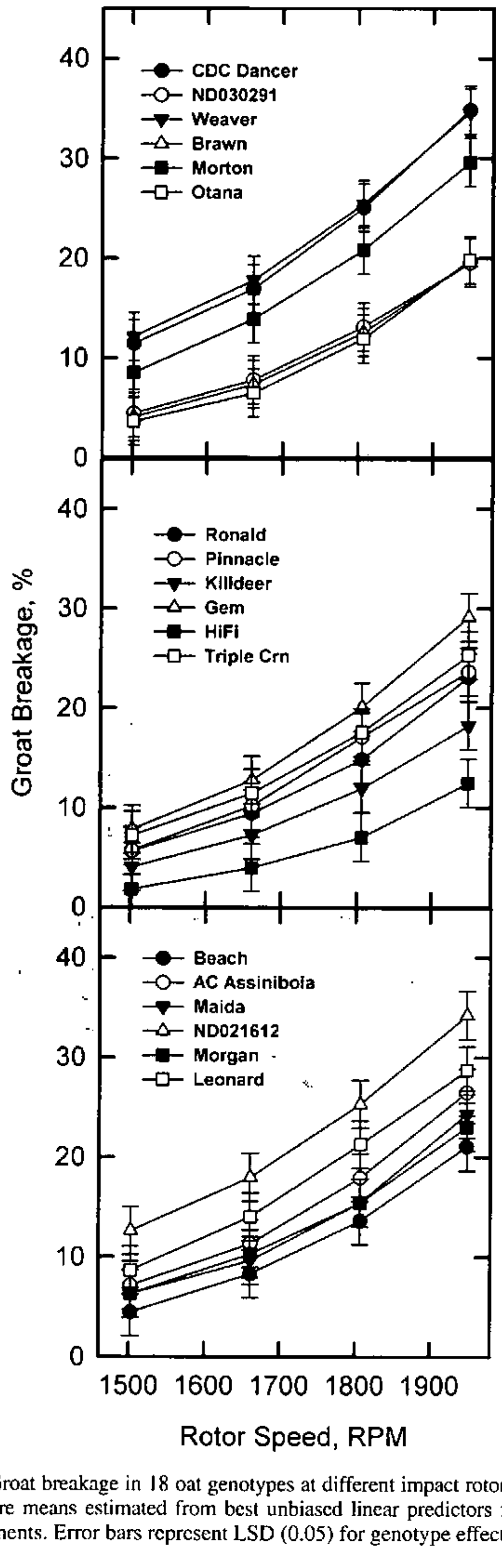

Fig. 3. Groat breakage in 18 oat genotypes at different impact rotor speeds. Values are means estimated from best unbiased linear predictors from six environments. Error bars represent LSD (0.05) for genotype effect.

Genotypic and environmental means of groat composition, including β-glucan, protein, and oil concentration are shown in Table II. HiFi and ND030291 had higher concentrations of β-glucan than the other genotypes. These same two genotypes and Beach had higher concentrations of oil than the other genotypes. Gem, ND030291, Maida, and Morton had higher concentrations of protein than other genotypes. The environment with the highest mean β-glucan concentrations was Fargo 2005. The environment with the lowest mean beta-glucan concentrations was Fargo 2006. The environment with the highest mean protein concentration was Williston 2006 and the environments with the lowest mean protein concentrations were Carrington 2005, Fargo 2005, and Fargo 2006. Fargo 2005 was the environment with the highest mean oil concentration and Williston 2006 was the environment with the lowest mean oil concentration.

Some interesting associations of groat composition (Table II) with dehulling characteristics at optimal rotor speeds (Table I) can be observed. The three genotypes most resistant to groat breakage (ND030291, HiFi, and Beach) were also the highest in oil. Two of these (HiFi and ND030291) were also the highest in β-glucan. Their increased resistance to breakage allowed them to be optimally dehulled at higher rotor speeds than many genotypes.

Genotypic correlations of dehulling characteristics with physical kernel characteristics (Table III) are not entirely consistent with the relationships just discussed because these were calculated at a single rotor speed (1,661 rpm), so that dehulling properties could be compared at constant stress conditions. This analysis indicated that test weight, groat proportion, and kernel density were highly correlated with dehulling efficiency and groat yield. Most other kernel components were also correlated with groat yield and dehulling efficiency. Broken groats were negatively correlated with oil, protein and β-glucan concentrations. Groat breakage was also positively correlated with many aspects of kernel size and density, including kernel mass, kernel volume, kernel density, groat mass, groat volume, groat density, kernel width, and kernel image area.

We compared weather data from the field stations with environmental mean values of dehulling characteristics in an attempt to determine how weather might affect dehulling. Very few significant correlations were observed (correlation table not shown). One particularly strong positive correlation was observed between groat breakage and potential evapotranspiration in July (Fig. 9). Potential evapotranspiration is an estimate of the maximum daily

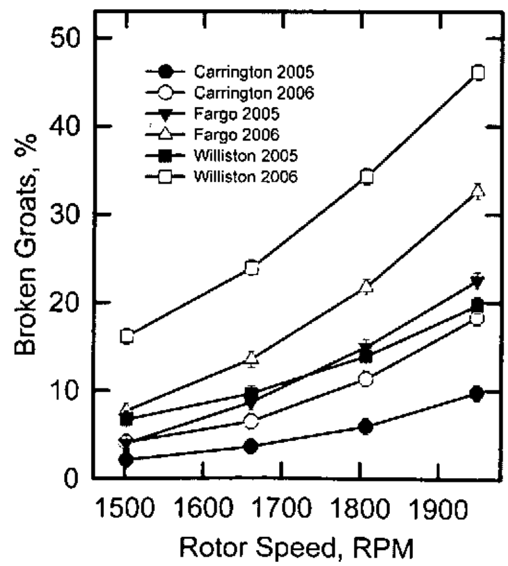

Fig. 4. Groat breakage in oats grown in six environments at different impact rotor speeds. Values are means estimated from best unbiased linear predictors from 18 genotypes. Error bars represent LSD (0.05) for environment effect.

crop water loss when water is readily available. It is calculated from the solar radiation, dew point temperature, wind speed, and air temperature using the Penman equation (Penman 1948) and is based on a crop like alfalfa. In most of our field plots, anthesis occurred close to July 1. Thus, results shown in Fig. 9 would suggest that hot dry weather during the grain filling process resulted in groats that were more brittle. Groat breakage was also significantly and positively correlated with high temperature in April. Like groat breakage, groat yield was correlated significantly with July potential evapotranspiration ($r = 0.930$, $P = 0.020$). Groat yield was also significantly correlated with rainfall in April ($r = -0.871$, $P = 0.020$), and June rainfall ($r = 0.884$, $P = 0.023$). Dehulling efficiency at any single rotor speed was affected significantly by environment (Fig. 2), but had no significant correlations with any weather condition analyzed here.

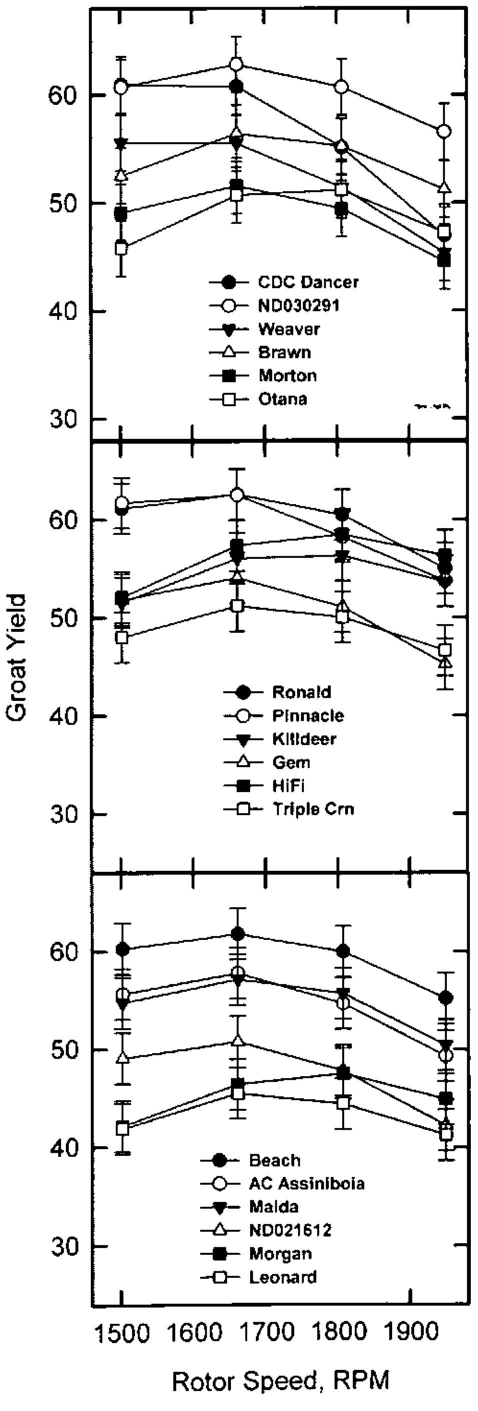

Fig. 5. Groat yields after dehulling 18 oat genotypes at different impact rotor speeds. Values are means estimated from best unbiased linear predictors from six environments. Error bars represent LSD (0.05) for genotype effect.

Variation observed here attributed to genotype and environment appears to follow patterns similar to those attributed to kernel size in our previous study (Doehlert and Wiessenborn 2007). In that study, it was concluded that dehulling efficiency and groat yield were most strongly affected by the test weight of the grain. Our previous study speculated that kernel density was the most likely characteristic of test weight associated with this effect, and our current study appears to confirm this.

A companion study to the current report (Doehlert et al 2009) established theoretical and empirical relationships between test weight to groat proportion and components of kernel density. Our current study appears to indicate that groat proportion and kernel density are the primary factors that may relate test weight to dehulling characteristics such as dehulling efficiency and groat breakage, although precise relationships cannot be derived, as can be for test weight and groat proportion (Doehlert et al 2009). Groat breakage appears to be primarily associated with environmental factors (Fig. 9). Potential evapotranspiration during the grain fill period of July alone could account for as much as 85% of the variation in groat breakage during dehulling. If potential evaporation during May is added to the regression equation, 97% of the variation in groat breakage could be accounted for. Amongst genotypic factors, significant correlations were found between groat breakage and groat composition components, including β-glucan, oil, and protein (Table III). Larger kernels, as measured by kernel mass, volume, and linear dimensions were also significantly correlated with groat breakage (Table III), but all of these factors together could only account for a relatively small proportion of groat breakage, especially when compared to environmental factors. Symons and Fulcher (1988) have also shown that larger oat kernels tend to break more during impact dehulling than smaller kernels.

Stepwise linear regression of dehulling efficiency with physical kernel characteristics listed in Table III indicated that only kernel density and percent groat breakage contributed significantly to the prediction of dehulling efficiency, and these together could account for only 42% of the total variation. None of the variation

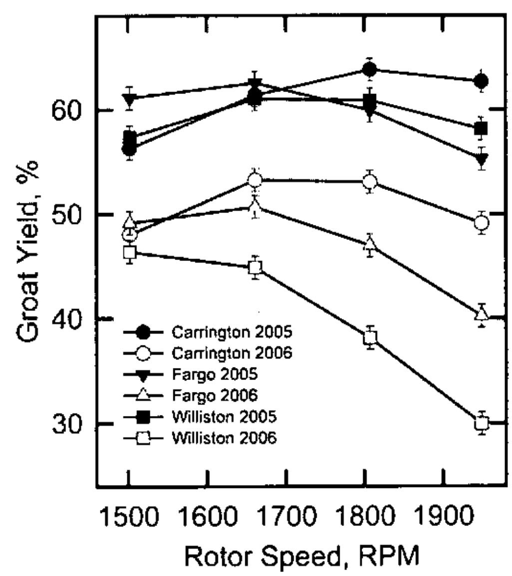

Fig. 6. Groat yield after dehulling in oats from six environments at different impact rotor speeds. Values are means estimated from best unbiased linear predictors from 18 genotypes. Error bars represent LSD (0.05) for environment effect.

in dehulling efficiency could be attributed to any weather condition tested (data not shown). Thus, descriptions gathered provide relatively little in predictive value for dehulling efficiency. Although we can safely say that dehulling efficiency is enhanced in high test weight grain with high kernel density, little more can be derived about the physical basis for dehulling efficiency from this data set.

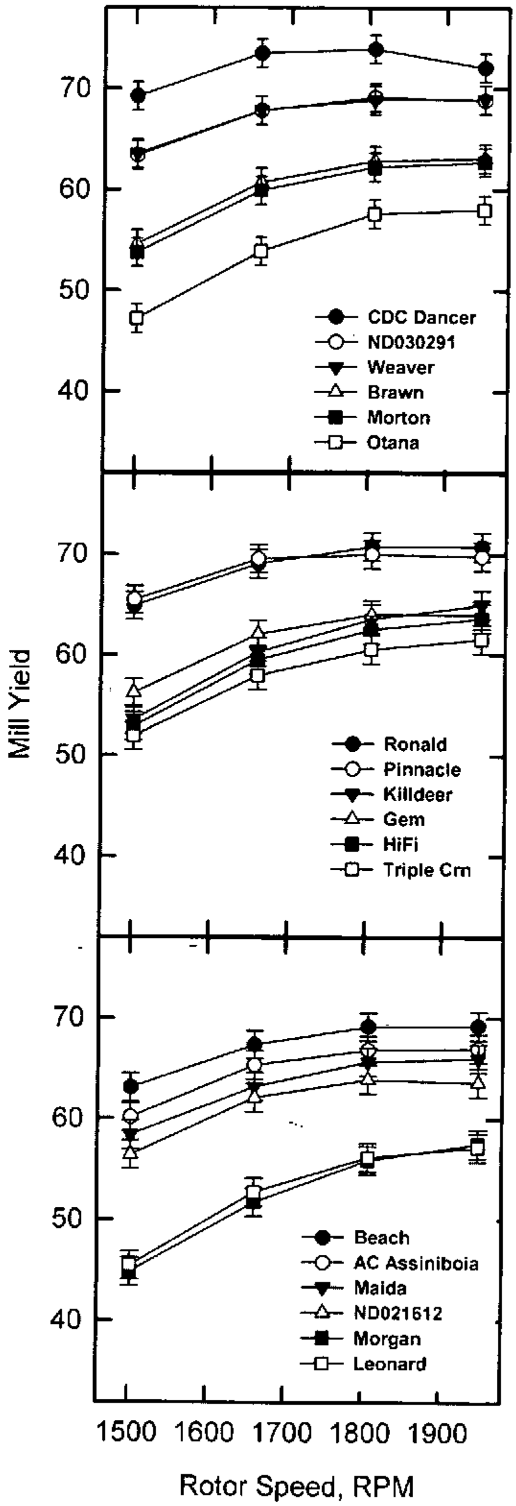

Fig. 7. Mill yield after dehulling of 18 oat genotypes at different impact rotor speeds. Values are means estimated from best unbiased linear predictors from six environments. Error bars represent LSD (0.05) for genotype effect.

The data set analyzed involves 18 genotypes at six environments. This represents a large selection of genotypes and an extensive sampling of germplasm currently in cultivation in North America. The sampling of environments is more limited; however, weather conditions at these locations were fairly diverse. In particular, conditions in 2006 were hotter and drier than those in 2005. The hotter and drier conditions may have led to decreased groat proportions (Table I), to which we attribute the decreased groat and mill yields (Figs. 6 and 8).

The observed association of groat breakage with potential evapotranspiration is novel. Potential evapotranspiration is calculated from the temperature and the vapor pressure deficit, and increases with increased temperature and decreased humidity. Our previous investigation into groat breakage noted an environment where groat breakage was particularly high (Doehlert and McMullen 2000). In the original report, the high rate of breakage was attributed to crown rust infection (Doehlert and McMullen 2000), but this was later amended when it was discovered that the location had been affected by sprout damage (Doehlert and McMullen 2003). In this study, it was the driest locations that were most susceptible to breakage, which is not consistent with either sprout damage or crown rust infection. The Fargo 2005 and the Carrington 2005 locations were moderately infested with crown rust, and these had low rates of breakage (Fig. 4, Table II). The physical characteristics that we measured were only moderately associated with breakage (Table III), thus we cannot readily assign specific traits responsible for the increased breakage in drought. Whereas an earlier study showed an association of β-glucan with groat hardness, in this study, both oil and protein concentrations were more strongly associated with resistance to breakage than β-glucan. Although all of the high β-glucan genotypes in this study exhibited low groat breakage, these lines were also high in oil, which had stronger association with resistance to breakage than β-glucan.

A relationship between rotor speed, dehulling efficiency and groat breakage was first shown by Brückner (1953) and Brückner et al (1956). Three previous works from this laboratory (Doehlert et al 1999; Doehlert and McMullen 2001; Doehlert and Wiessenborn 2007) developed the concept that increased mechanical stress during dehulling increases groat breakage. Browne et al (2002) developed similar concepts with a compressed air oat dehuller. Engleson and Fulcher (2002a,b) reported analyses of physical stress upon groat breakage, as might occur during dehulling.

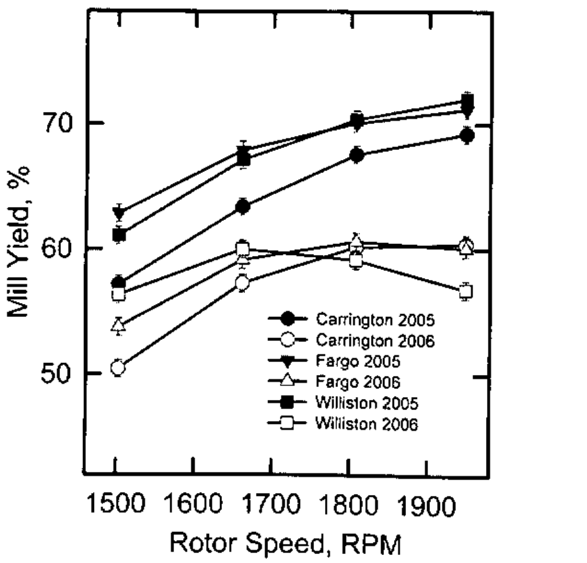

Fig. 8. Mill yield after dehulling of from six environments at different impact rotor speeds. Values are means estimated from best unbiased linear predictors from 18 genotypes. Error bars represent LSD (0.05) for environment effect.

One item of interest from their study were positive correlations between phenolic compounds and resistance to groat breakage. We previously reported concentrations of avenanthramides (avn) from samples used in this study for an independent study (Wise et al 2008). Although ranking of environmental mean avn concentrations mirrors closely the ranking of groat breakage, and July potential evapotranspiration (Fig. 9), the actual avn concentrations were not significantly correlated with groat breakage ($r = -0.43$, $P = 0.28$).

However, it would appear that the correlation would become significant if more environments were sampled. Wise et al (2008) attributed the increased avn concentrations in less hot, dry environments to induction by disease. Phenolic compounds, such as those described by Wise et al (2008) or Engleson et al (2002a,b) have the potential of improving cell wall strength through various mechanisms of cross-linking. Our current information cannot distinguish whether hot, dry conditions make groats more brittle, or wetter conditions make groats less brittle, possibly by strengthening their cell walls.

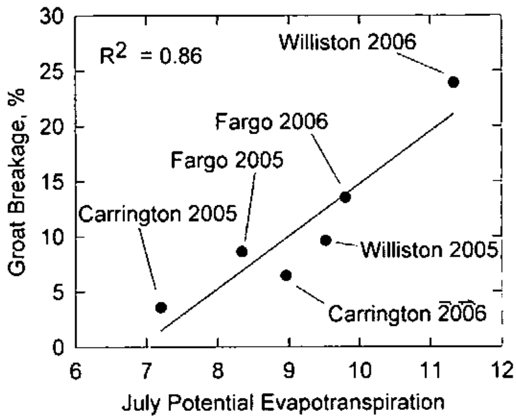

Fig. 9. Relationship between % broken groats after dehulling with an impact dehuller with a rotor speed of 1,661 rpm and potential evapotranspiration from 6 North Dakota oat cultural locations in July. Line represents a linear regression of the data. $R^2 = 0.86$ significant ($P = 0.02$).

TABLE II
Genotypic and Environmental Means of Groat Composition[a]

	β-Glucan (%)	Protein (%)	Oil (%)
Genotype			
AC Assiniboia	4.50	17.5	8.16
Beach	5.40	17.7	9.37
Brawn	5.09	18.4	7.84
CDC Dancer	4.87	17.0	7.13
Gem	5.24	20.2	6.57
HiFi	6.62	18.2	8.95
Killdeer	5.13	17.9	7.72
Leonard	4.20	18.3	7.26
Maida	4.64	19.5	8.84
Morgan	4.75	16.6	7.02
Morton	4.92	19.3	7.52
ND021612	5.09	17.4	7.07
ND030291	6.99	19.7	8.83
Otana	5.28	18.1	7.61
Pinnacle	4.78	16.6	8.13
Ronald	5.37	17.8	8.91
Triple Crown	5.21	18.8	7.85
Weaver	5.04	16.9	8.00
LSD (0.05)	0.34	0.60	0.32
Environment			
Carrington 05	5.39	17.1	8.27
Carrington 06	5.25	19.4	7.61
Fargo 05	5.54	17.0	8.60
Fargo 06	4.75	17.1	8.02
Williston 05	5.02	18.0	8.05
Williston 06	5.10	19.9	7.06
LSD (0.05)	0.45	0.50	0.56

[a] Expressed on a dry weight basis. Means estimated from best linear unbiased predictor.

TABLE I
Genotypic and Environmental Means of Dehulling Characteristics of Oat Genotypes[a]

	Groat Proportion (%)	Dehulling Efficiency (%)	Broken Groats (%)	Groat Yield (%)	Mill Yield (%)	Optimal Rotor Speed (rpm)
Genotype						
AC Assiniboia	73.5	88.4	10.2	58.4	65.0	1680
Beach	73.8	90.8	7.7	62.3	67.2	1681
Brawn	69.1	88.6	8.9	56.1	61.4	1740
CDC Dancer	77.5	92.0	13.4	61.9	72.6	1614
Gem	69.5	87.6	11.6	54.0	61.0	1657
HiFi	68.6	90.4	5.9	58.9	62.2	1796
Killdeer	71.4	87.1	9.3	56.6	62.2	1758
Leonard	66.7	81.3	15.7	45.3	54.0	1732
Maida	72.3	88.7	10.9	57.4	64.3	1701
Morgan	67.4	81.8	10.7	49.0	55.0	1756
Morton	69.0	86.6	12.2	52.6	59.8	1673
ND021612	71.1	87.3	16.7	51.4	62.1	1673
ND030291	73.1	92.3	6.9	63.5	67.8	1713
Otana	66.7	85.5	7.9	52.5	56.9	1765
Pinnacle	74.1	80.8	7.7	52.6	67.4	1623
Ronald	75.6	80.7	8.6	63.1	68.8	1679
Triple Crown	68.3	86.9	11.4	52.6	59.5	1730
Weaver	75.1	87.6	14.2	56.4	65.8	1622
LSD (0.05)	2.3	3.0	3.5	3.5	3.5	79
Environment						
Carrington 05	77.1	87.7	5.8	62.3	65.9	1821
Carrington 06	68.2	88.7	7.9	54.6	59.3	1727
Fargo 05	75.2	87.9	8.4	61.7	66.9	1680
Fargo 06	67.8	88.4	11.6	52.2	59.2	1652
Williston 05	76.4	87.9	11.2	60.2	67.2	1747
Williston 06	66.0	87.7	18.4	47.2	58.4	1570
LSD (0.05)	4.3	ns	3.3	2.6	3.2	79

[a] Values from 18 oat genotypes grown at six environments when dehulled at an optimal rotor speed for maximal unbroken groat yield. Means estimated from best unbiased linear predictor.

TABLE III
Genotypic Correlations of Physical and Chemical Oat Kernel Characteristics with Dehulling Properties[a,b,c]

Characteristic	GY	DHE	Broken
Dehulling efficiency	–0.884**	. . .	. . .
Broken groats	–0.204	0.262*	. . .
Test weight	0.805**	0.741**	0.236*
Groat proportion	0.780**	0.697**	0.279**
Beta-glucan	0.166	0.186	–0.283**
Protein	0.259*	0.022	–0.429**
Oil	0.403**	0.255*	–0.472**
Kernel mass	0.147	0.295**	0.473**
Kernel volume	–0.222*	–0.097	0.339**
Kernel density	0.692**	0.742**	0.242*
Packing efficiency	0.322**	0.345**	0.123
Groat mass	0.446**	0.518**	0.392**
Groat volume	0.344**	0.389**	0.293**
Groat density	0.306**	0.437**	0.343**
Hull mass	–0.467**	–0.378**	0.182
Hull volume	–0.600**	–0.516**	0.135
Hull density	0.200	0.268*	0.065
Kernel length	–0.447**	–0.407	0.043
Kernel width	–0.245*	–0.023	0.374**
Kernel image area	–0.464**	–0.311	0.226*

[a] Dehulling characteristics taken at constant rotor speed (1,661 rpm).
[b] * and ** Significant at $P < 0.05$ and $P < 0.01$.
[c] GY, groat yield; DHE, dehulling efficiency; Broken, % broken groats.

CONCLUSIONS

Eighteen oat cultivars grown in six different environments dehulled at four different rotor speeds responded differently in an impact oat dehuller. Dehulling efficiency and groat breakage both increased with impact rotor speed. Groat yield, which increased with improved dehulling efficiency and decreased with groat breakage, was optimal at specific rotor speeds that varied with genotype and environment. Dehulling efficiency appeared most strongly affected by test weight, kernel density and groat proportion. Groat breakage was lower in grain with higher protein, oil and β-glucan concentrations, and appeared to be strongly affected by the environment. Hot and dry conditions during the grain fill period of the oats (July) appeared to be associated with increased groat breakage during dehulling. In general, oats with high test weight and kernel density could be dehulled with high efficiency at slower rotor speeds, which minimized groat breakage and maximized groat yields.

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